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1. FACTORS OF ELECTRICITY

a. Basic Composition of Electricity

(1) Scientists tell us that everything in the world is in essence made up of electrical charges.

(a) There are two types of electrical charges, which have been arbitrarily called negative charges and positive charges.

(b) When these charges begin to concentrate in one place, or to move about, we call this electricity, electrical flow or electrical current.

(2) On automotive equipment, electricity is used for lighting, it operates the starter, produces high voltage spark at the spark plugs in gas powered vehicles, and operates gauges and various other components.

b. Basic Composition of Matter

(1) Matter is described as all material substances which occupy space or have mass.

(2) If we study the world about us, we find that everything including solids, liquids and gases is made up of tiny particles called atoms.

(a) Atoms combine in small groups of two or more to form molecules.

(b) Molecules are made up of atoms and these atoms can be further subdivided.

(c) When we divide atoms, we find that they contain smaller particles, some of which have positive electrical charges and others with negative electrical charges.

(3) There are over 92 known basic materials in the universe. These materials are called elements.

(a) Iron is one element, copper, aluminum, mercury, etc. are other elements.

(b) An element gets its name from the fact that it cannot be broken down into smaller elements or substances.

(c) In other words, the basic elements are the building material from which the universe is made.

(4) Strangely enough, if we take any of the known elements and study them closely, we find that they all contain the same basic particles having positive and negative electrical charges.

(a) A proton is a basic particle having a single positive charge. When combined into a group, they produce a positive electrical charge.

(b) An electron is a basic particle having a single negative charge. When combined into a group, they produce a "negative" electrical charge.

Structure of an Atom,
(Figure 1)

(c) A neutron is a basic article having no charge. some scientists believe that neutrons are actually an electron and a proton combined in perfect electrical balance.

(6) Figure 2 illustrates One of the fundamental rules in the study of electricity that will aid in understanding electrical current is the rule of charges, which states:

(a) "Like charges repel" each other and "unlike charges attract" each other.

(b) The rule of charges does not apply to the neutrons in the atom because they have no electrical charge.

Rules of Electrical Charges

(Figure 2)

(7) Though neutrons have no electrical charge, they do have the ability to cancel out the repelling forces between protons in an atomic necleus and thus hold the nucleus together.

(a) Figure 3 illustrates the structure of the atoms and may be compared to the solar system, with the sun at the center or nucleus.

(b) The planets (Earth, Mars, etc.) revolving around the sun, may be compared to the electron in orbit around the nucleus of the atom.

Structure of the Copper Atoms
(Figure 3)

c. <u>Composition and Classification of Elements</u>

(1) As previously stated there are over 92 basic elements which are made up of atoms. Let us examine more closely the composition of elements that we are all aware of.

(2) The copper element illustrated in Figure 4, contains 29 protons and 29 electrons and therefore is identified as 29 on the atomic scale.

(a) The center of the copper atom contains the 29 protons and the neutrons that make up the nucleus or center. Our concern, however, is the electron because it is the particle that does the work in automotive circuits.

(b) As more electrons and protons are added to the atom, the circular path or orbit around the center of the atom changes.

Copper Atom
(Figure 4)

(c) The 29 electrons in the copper atom are distributed in four separate rings, with each ring a greater distance from the center.

(d) The three rings of electrons that are located nearest the center are called bound electrons because they cannot be moved from orbit easily. In other words they are strongly attracted to the center by the protons.

(e) Figure 4 illustrates a single electron in the outer ring and is the greatest distance from the center. It is called the "free electron." Because of the great distance from the center, the free electron is not as strongly attracted by the protons, and therefore can be made to move easily from its orbit.

(f) Recalling the rule of charges; unlike charges attract and like charges repel, you may ask, what keeps the electrons from moving into the center of the atom?

(g) Opposing the attraction between the two particles and thus preventing the electron from moving into the center of the atom, is the centrifugal force caused by the circular path of the electron.

1. This is the same sort of balance you would get if you were to whirl a ball tied to a string around your head.

2. The centrifugal force exerted tries to move the ball out of its circular path, but the attractive

force of the string retains it.

Copper Atom
(Figure 4)

3. The centrifugal force of the electrons move them away from the center of the atom, until that force is equal to the attractive force of the protons. When the two forces are equal the atom is balanced and the electrons will continue to move around the protons.

4. The attractive force between the electrons and protons sometimes is not strong enough to hold the electron in the outer ring and the electron will break "free" and fly away.

(h) The element copper contains but one electron in the outer ring of the atom and that electron can easily be moved from its orbit and become a free electron.

Copper Wire
(Figure 5)

(i) (Figure 5) A copper wire for example, contains countless billions of free electrons that can be made to leave their atoms when an attractive force is applied to the wire.

d. Charges in Motion

(1) Electrons can be made to leave their atoms in most materials, when a force is applied.

(2) (Figure 6.) When numerous electrons break free from their atoms and gather in

one area, we call that effect a charge of electricity.

(3) When electrons begin to move in one direction, (such as along a wire, for example) we call that effect a flow of electricity or electric current.

(4) Like electrical charges repel each other and unlike electrical charges attract.

Copper Wire with Attractive Forces

(Figure 6)

(5) Electrons such as those contained in the copper atom are always in motion around the center of the atom.

(6) The number of electrons in the outer ring of the atom determines to a great extent the electrical characteristics of the element.

(7) Atoms, that are present in all materials, must have the same number of protons as electrons to be satisfied.

(a) If a free electron was to leave an atom, the atom would be deficient in electrons and therefore have a positive electrical charge, caused by the vacancy or hole left behind.

(b) If an atom contains more electrons than it has protons, it is more negative than positive, and therefore has a negative electrical charge.

(c) So, what you have created here are two charges, a free electron (negative charge), and a free hole (positive charge). It does not matter which of the charges you follow along a wire or conductor.

e. Conductors

(1) The most common conductor used in automotive circuits is copper.

(2) Copper contains countless billions of electrons and the electrons in the center rings are called "bound electrons." Only the electron in the outer ring is illustrated and that is one we will discuss at this time.

(3) Keeping in mind the rule of charges, unlike charges attract and like charges repel.

Current Flow in a Copper Conductor
(Figure 7)

(a) Looking at the illustration of the positive charge at the end of the copper wire, (that is the attractive force) in Figure 7 we find that the free electron in the atom of the copper conductor is attracted to the positive electric charge and is pulled away from its atom.

1. When this occurs, the atoms nearest the positive charge are no longer in electrical balance because they have lost the free electron in the outer ring.

2. When the atoms in the conductor near the positive end lose their electrons, they become positively charged because they are deficient of the free electron.

3. The atom nearest the positive charge now passes an attractive force that causes the electron in the outer ring of the neighbor atom to be attracted to it.

4. The neighbor atom will give up its electron to the first atom and at the same time collect another electron from another neighbor.

(b) The net result of this action is a movement of electrons, through a wire, with the negative charge at the opposite end of the wire providing a repelling force that is equal to the attractive force of the positive charge.

(c) Electrons will continue to flow in a wire as long as the positive and negative charges are maintained at the ends of the wire.

(d) The continuous flow of electrons in a conductor is called "dynamic electricity." Electricity is the flow of electrons from atom to atom in a conductor. In other words, current is none other than a flow of electrons through a conductor or component.

(4) Material with less than four electrons in its outer ring is considered to be a conductor.

(a) If the material has more than four electrons in its outer ring, it is considered to be an insulator.

(b) Examples of materials that are used as insulators in automotive circuits are: porcelain, rubber, and plastic.

1. Insulators are used in electrical circuits to keep the current flow in its proper path.

2. Insulators to be used on wires are determined by the amount of electrical pressure that is applied to the circuit.

Flow of Water Compared to
Flow of Current
(Figure 8)

f. Electric Current Moving Through a Conductor

(1) (Figure 8) To aid in our understanding of how electricity behaves, we can compare the flow of electricity to the flow of water through a hose. Before water will flow through the hose, it must have pressure to overcome resistance. When you turn on the faucet (high pressure side of the hose) [voltage], the water pressure overcomes the inertia (resistance to change) of the still water in the hose.

(a) This pressure moves a certain quantity of water, depending upon the size of the hose. Electric current in a wire behaves similarly to the water flowing in the hose.

(b) Figure 8 illustrates the flow of water compared to the flow of current. The low pressure side of the hose represents the attractive force of the positive (holes or lack of electrons) charges.

(c) The high pressure side of the hose represents the pressure or voltage caused by the repelling forces that is placed on the conductor by the negative charge. The quantity of electrons flowing in the conductor is called amperage (also called current).

(2) The water hose is the conductor that directs the movement of water in the same manner that an electrical conductor contains and directs the movement of electrons.

Flow of Water Compared to Flow of Current
(Figure 8)

(a) The movement of electrons, or current flow, will encounter some resistance along its travel through its conductor. How much resistance would depend upon the physical properties of the conductor.

(b) The hose with a small diameter has more resistance to flowing water than the hose with a larger diameter.

g. Methods of Producing Electricity and Factors that Control Current Flow in Automotive Electrical Systems

(1) There are two methods used to produce the energy required to cause current to flow in conductors of automotive circuits. The methods are:

(a) the mechanical method used in the alternator.

(b) the chemical method used in the automotive storage battery.

(2) The storage battery consists of lead plates that are immersed in a solution of sulfuric acid and water. When charged, the chemical reaction between the plates creates the potential energy or force necessary to cause current flow.

(3) Think of the battery plates as the attractive and repelling forces at each end of the conductor.

(a) Looking at Figure 9, we see that the positive plate is identified with a (+) mark and the negative plate is identified with a negative (-) mark.

Current Flow
(Figure 9)

(b) That is because the negative plate (when charged) has an excess of electrons. In other words, the atoms that are contained in the active material of the negative (-) plates have more electrons than protons and therefore have a negative electrical charge.

(c) The positive plate is deficient in electrons. The atoms that are concentrated in the active material of the positive (+) plate contain more "protons" than electrons and therefore have a positive "electrical charge."

(d) The positive and negative electrical charges that are collected at the ends of the conductor provide the repelling and attractive forces that are necessary to cause electrons to leave their atoms.

(4) Again recalling the rule of charges, "unlike charges attract" we will now refer to the positive battery plate.

(a) The electrons contained in the atoms at the negative end of the conductor are attracted by the positive charged atoms that are concentrated at the positive battery terminal.

(b) That attraction causes the free electrons in the conductor (that is attached to the positive battery post) to leave their atoms.

1. When electrons leave the atom, it loses its electrical balance and exerts a strong positive force on its neighbor atom.

2. The neighbor atom gives up its electron to the first atom and collects another electron from its neighbor, on down the conductor.

(5) Looking at the negative (-) battery plate that contains an excess of electrons and recalling that "like charges repel," look what happens here.

(a) The electrons that are contained in the atoms at the negative end of the conductor, are repelled by the negative charged atoms that are concentrated at the negative battery terminal.

(b) The repelling force of the negative battery plate in conjunction with the attractive force of the positive battery plate causes the electrons to move from atom to atom in the conductor.

(c) As stated earlier, any charges in motion, be it positive or negative is described as current flow. When troubleshooting an automotive electrical system, it's much easier to follow the positive lead from the battery to the using component to vehicle ground, vice the other way around.

h. Current

(1) We have established the fact that current is nothing more than the movement of electrons from atom to atom in a conductor; and to cause that movement, a force is required.

(2) In the early days of electricity, current was referred to as intensity. Current is identified with the letter "I".

Current Flow
(Figure 10)

(a) The unit of measure for current is the ampere and it is measured with an ammeter as illustrated in Figure 10.

(b) The ammeter, when connected to the circuit correctly, measures the number of electrons that pass a given point in the circuit.

(c) We think of one ampere as a rather small amount of current flow; however, it is about the amount required to light a 120 watt light bulb.

(d) Actually, one ampere is a tremendous flow of electrons. More than 3 billion electrons are required to pass a given point in one second
to equal one ampere of current flow.

(e) Current is one of the most important factors of electricity
because it is the one that does the work for us.

(f) In order for current to flow in an electrical circuit, it must have a complete path to follow. The path must be complete to and from the source of energy; in this case, the battery.

1. Looking at Figure 10, we see a conductor connected to the positive voltage source.

2. Following the path, we see that current flows from the source through the main element (bulb) and back to the negative terminal of the source.

3. The source of the energy in automotive circuits is the storage battery or alternator.

(g) Although current is one important factor of electricity, there is one other factor that is equally important; that factor is voltage.

j. Voltage. In the early study of electricity, voltage was called many things.

(1) Voltage was first referred to as "potential energy" because it had the ability to perform work by causing electrons to move through a wire.

(2) Sometimes voltage was referred to simply as electrical pressure.

(3) Today the force that is required to cause current to flow is referred to as "voltage" or "electromotive force" (emf). Voltage is identified with the letter "E".

Voltage (Figure 10)

(4) Regardless of what we call voltage, it is the invisible force that is required to have current flow in any electrical circuit.

(5) The unit of measure for voltage is the volt, just as pounds per square inch is used to measure water pressure.

(6) The meter used to measure voltage is referred to as a voltmeter.

(7) The concept of voltage is sometimes difficult to understand, but the following comparisons are often helpful.

(a) Voltage is like a stretched rubber band or a spring that has been compressed.

(b) It represents potential energy or the ability to do work.

(c) When a storage battery is charged, potential energy exists between the negative and positive battery posts even though no current consuming devices are connected.

<u>1</u>. Voltage simply "stands by," waiting to expend its potential energy whenever current consuming components are connected to the voltage source.

2. Thus, voltage can exist in automotive circuits without current, but current cannot exist without voltage, because voltage is the electromotive force that pushes the current along the conductor and through the components.

3. To assist in understanding the concept of voltage, let's compare the automotive storage battery with water storage tanks as illustrated in Figure 11.

Electrical Pressure Compared
to Water Pressure
(Figure 11)

(d) We know that current will not move through a conductor unless a difference in electrical pressure exists at each end of the conductor.

(e) Looking at the water tank on the right in Figure 11, we find it is filled with water and the other is empty.

(f) We will assume the tank that is full of water has a pressure of 12 PSI.

(g) The tank on the left is absent of water, and because of that we will assume that it has a pressure of zero.

(h) The plates in the automotive storage battery are electrically equivalent to the two water tanks.

1. The negative battery plate is electrically equivalent to the full tank, because it has an excess of electrons and applies pressure to the circuit.

2. The positive battery plate is electrically equivalent to the empty tank because it has a shortage of electrons and provides an attractive force to the conductor or circuit.

3. If a voltmeter was connected across the two battery posts, we would find the difference in electrical pressure to be 12 volts.

4. If we were to attach a pressure gauge to the water tanks, the full tank would indicate 12 PSI, and the empty tank zero. A difference of 12 PSI of water pressure would be indicated.

(i) Located at the bottom of the storage tanks in Figure 12 is a pipe and valve, which connects the two tanks and provides a means for controlling the movement of water.

(j) Now we will open the valve and see what happens to the water. This action could be compared to turning on the lights of your automobile without the engine running.

1. With the valve open, water will flow from the full tank to the empty tank.

Electrical Pressure Compared
to Water Pressure
(Figure 12.)

2. This flow will continue until the pressure is equal in both tanks or both tanks contain the same amount of water.

3. The same is true for the automotive storage battery. With the lights on and the engine not running, the flow of electrons will continue until both plates have the same amount of electrons, or in other words, until the battery becomes discharged.

4. So, the comparison is this, when both water tanks have the same amount of water or both battery plates have the same number of electrons, all action stops. The lights go out or the transfer of water stops.

(k) Looking at the water tanks in Figure 12, we now observe that both tanks contain the same amount of water and there is no difference in pressure between the two tanks.

1. If we place a voltmeter across the battery posts, we would find no difference in electrical pressure and the battery would be in a discharged state. This is because the active material in the negative and positive plates have the same numbers of electrons and therefore have lost the repelling and attractive forces that are necessary to cause current flow.

2. Voltage, therefore, is produced between two points when a positive charge exists at one point and a negative charge exists at the other point.

3. The greater the deficiency of electrons at the positive battery post and the greater the excess of electrons at the negative battery post, the greater will be the voltage.

4. The voltmeter simply measures the difference in electrical pressure between the negative and positive voltage source.

(l) There are two important facts to remember. One, you must have voltage present in an automotive circuit in order to have current flow. Two, voltage is the electromotive force required to cause current flow through any circuit or components.

k. Resistance. All conductors and components in circuits offer some measure of resistance. The resistance results primarily from two factors.

(1) One factor is that each atom resists the removal of an electron because of the attraction exerted on the electrons by the protons in the core of the atom.

(2) The other factor involves the countless collisions that occur between electrons and atoms as the electrons move through the conductor. These collisions create resistance and cause heat to appear in any conductor or component in which a current is flowing.

(3) How good a conductor is will be determined by its lack of resistance to the flow of current.

(a) To honor the achievements of Dr. George Simon Ohm, the standard unit of measurement for resistance is called an OHM.

(b) Resistance is measured with an ohmmeter and is identified by the letter "R." Frequently it may be identified by the Greek letter "omega" as W.

(4) There are many factors that determine the resistance of a conductor.

(a) One of these is the number of free electrons in the conductor.

(b) Silver has the most free electrons and is therefore the best conductor, but it is too expensive for use in automotive circuits.

(c) Copper is a good conductor and is the most common conductor used in automotive circuits.

Resistance
(Figure 13)

(5) Other than the properties of the conductor, there are more common factors that you as automotive mechanics should keep in mind about conductors and resistance.

(a) As illustrated in Figure 13, the size or cross section of
the conductor will also determine its resistance to current flow.

Resistance
(Figure 13)

1. The larger the diameter of a conductor, the more electrons it has; and therefore, a large diameter conductor will conduct a greater amount of current than a small diameter conductor.

2. An example of conductor size is the battery to starter cable. The starter cable is the largest conductor (diameter wise) used in the automotive electrical system because the starter requires a larger amount of current than any other electrical component.

(b) The resistance of wires used as conductors is also dependent upon the length of the wire.

1. If the length of the wire is doubled, the resistance between the wire ends is doubled.

2. In other words, the longer the wire the greater the resistance and the shorter the wire the less the resistance. Of course, we are talking about wires of the same size in this case.

(c) Another important factor affecting the resistance of a wire is temperature. As temperature increases, the resistance of the wire will increase.

(d) Resistance is one of the most important electrical factors, because current flow is in direct proportion to resistance.

1. If resistance in an electrical circuit increases, current flow will decrease in proportion to the increase in resistance.

2. If resistance in an electrical circuit decreases, current flow will increase in proportion to the decrease in resistance.

(e) There are three important facts to remember about wires used for conductors in automotive circuits:

1. The longer the wire, the greater the resistance.

2. The smaller the wire, the greater the resistance.

3. The hotter the wire gets, the greater the resistance.

(6) Keeping in mind the three factors of electricity; voltage, current and resistance, it is important to remember that these factors are

closely related in all automotive circuits. There are a few basic rules to keep in mind that may help in understanding current flow in electrical circuits.

(a) If resistance in the circuit remains the same and voltage is increased, the result will be an increase in current flow.

(b) If resistance in the circuit remains the same and voltage is decreased, the result will be a decrease in current flow.

(c) If voltage in the circuit remains the same and resistance is increased, the result will be a decrease in current flow.

(7) Every automotive electrical circuit that is complete has current, voltage, and resistance.

(a) The battery or alternator supplies the voltage which forces the current through the circuit.

(b) The circuit consists of wires, straps, lights, switches and other using components, which in turn make up the resistance.

(c) Switches are used to open and close the circuits.

Electrical Factors and Units of Measure
(Figure 14)

(8) To isolate malfunctions in automotive circuits and components, you must be able to measure the value of each electrical factor.

(a) Amperage is identified by the letter "I"; the unit of measure is the ampere and it is measured with an ammeter.

(b) Voltage is identified by the letter "E"; the unit of measure is the volt and it is measured with a voltmeter.

(c) Resistance is identified by the letter "R"; the unit of measure is ohms and it is measured with an ohmmeter.

2. TYPES OF AUTOMOTIVE ELECTRICAL CIRCUITS

a. Automotive Electrical Circuits. There are three types of circuits used in automotive electrical circuits. They are called series circuits, parallel circuits, and a combination of the two that is called a series-parallel circuit.

b. Schematic Diagrams. Wiring diagrams located in our technical manuals used in troubleshooting automotive electrical systems are called schematic diagrams. Various symbols are used on the diagrams to identify electrical components.

c. Simple Circuit

(1) The most simple circuit must have wires to conduct the current; a source of volage, such as a battery or alternator and, a using component such as a light bulb.

Electrical Symbols
(Figure 15)

(2) A circuit can be illustrated in three basic ways.

(a) Circuit "A" in Figure 16 shows a simple, two-wire series circuit. The battery is the voltage source. Two wires are used to conduct the current to and from the source, and a light bulb is illustrated as the using component that consists of the resistance.

Simple Circuit
(Figure 6)

(b) Circuit "B" in Figure 16 shows a simple single wire circuit. This is the type that is used on automotive electrical systems. The metal parts of the vehicle take the place of the second wire and provide a common ground to complete the circuit back to the voltage source.

(c) Circuit "C" in Figure 16 is the same as the single wire system described above. The only difference is that symbols are used to identify circuit components.

1. The battery symbol indicates a 12 volt battery is being used.

2. The resistance symbol is used to identify the using component.

3. The ground symbol is used to identify the point that the circuit is connected to a common ground.

(3) For any electrical circuit to function and be complete, it must have voltage, current, and resistance.

d. <u>Series Circuit</u>

(1) Looking at circuit "A" of Figure 17, we see a two-wire series circuit with a switch to control the circuit by turning it on and off.

(2) Two bulbs are connected to the circuit as using components.

(3) In a series circuit, the current has only one path to flow to and from the source.

Series Circuit
(Figure 17)

(4) The two lamps are connected end to end and are said to be connected in series.

(a) You may recall the Christmas tree lights used on Christmas trees, the type that when one light goes out, they all go out.

(b) They go out because each light is connected end to end or in series and when one bulb burns out the circuit becomes open and current cannot flow in an open circuit.

(5) Looking at circuit "B" in Figure 17, we see the same circuit displayed using the single wire system with the metal parts of the vehicle providing the ground circuit.

(6) Circuit "C" in Figure 17, is the single wire circuit that is illustrated in Circuit "B". The only difference is that symbols are being used to identify components and resistance.

e. Parallel Circuit

(1) The two-wire parallel circuit illustrated in Figure 18 is different than the series circuit in that:

(a) Several components are connected to the same voltage source.

(b) As illustrated in circuit "A", these components are connected parallel or side by side.

Parallel Circuit
(Figure 18)

(c) The parallel branches provide multiple paths for current flow. The circuit illustrated shows four separate parallel branches.

(d) When components are connected parallel (side-by-side) in this manner, each branch functions as an individual circuit and the current flow in each branch will be in direct proportion to the resistance of that branch.

(e) Due to the fact that each parallel branch is connected to the same voltage source, one bulb can burn out without any other branch going out as they do in the series circuit.

(2) The single-wire parallel circuit illustrated is representative of lighting systems used on automotive vehicles.

Parallel Circuit
(Figure 18)

(a) A switch is used to turn the lights on and off. Switches may be installed to turn off all lights in the parallel branches at the same time or installed in individual branches to control each light.

(b) In a series circuit, installing a switch at any point in the circuit will control all lights because the current has only one path to follow.

(c) The current flow in the single-wire system is a little different from the two-wire system in as much as it relies entirely on the metal parts of the vehicle for a conductor back to the voltage source.

(3) Circuit "C" shown in Figure 18, is the same as the single wire circuit just discussed, the difference being that symbols are used to identify components in the circuit.

f. <u>Series-Parallel Circuit</u>

(1) Circuit "A" in Figure 19 the shows an illustration of a two-wire series-parallel circuit.

(a) Notice the location of the components; one light is connected in series with the four parallel branches.

(b) In this circuit arrangement, the current must flow through the light that is connected in series and then it is divided between the four parallel branches.

Series Parallel Circuit
(Figure 19)

(c) Part of the voltage will be used by the light that is connected in series and the voltage remaining will be available at the parallel branches.

1. Let's assume that the voltage available to power the circuit is 12 volts and the voltage expended by the light connected in series is 6 volts.

2. In this example, the remaining voltage would be 6 volts and that is the voltage that is applied to each of the parallel branches.

(2) Circuit "B" in Figure 19 is a representative of single-wire circuits used on automotive vehicles.

(a) Keep in mind that the distribution of voltage in a series- parallel circuit is a little different than a straight parallel circuit.

(b) In the parallel circuit, the voltage applied to each branch was the same as source voltage. However, in the series-parallel circuit, the applied voltage will be lower than source voltages because some of the voltage will be used by the components that are in series with the parallel branches.

(3) Circuit "C" in Figure 19 is the same as the single-wire circuit except symbols are again used to identify circuit components.

g. Automotive Circuits

(1) All major components in an automotive circuit are in parallel with the battery or alternator, while other components such as switches and relays are in series.

(a) Looking at the illustration of the starter in Figure 20, we see that the starter motor is parallel across the battery, while the switch

that controls the starter is in
series with the voltage source.

Automotive Circuits
(Figure 20)

(b) The next component is the ammeter. It is connected in series with all components in the electrical system except the starter.

(c) The alternator is connected parallel across the circuit.

(d) The ignition switch is connected in series with the starter.

(2) It is important to remember when troubleshooting the electrical system of automotive vehicles, that the single-wire system is used exclusively.

(a) Each circuit is grounded to some metal part of the vehicle.

(b) As illustrated in Figure 20, the frame or other metal parts take the place of the second wire and provides a common ground for the current to return to the source.

h. Rules that Pertain to Electrical Circuits

(1) Basic Rules. There are basic rules that apply to everything you do in the military and civilian community.

(a) Rules or regulations are necessary to protect the rights of all people.

(b) There are some fundamental rules that apply to electrical circuits that the automotive mechanic must be familiar with in order to understand the operation of electrical circuits and components and be able to safely test them.

(c) The rules for electrical circuits are a little different for each type of circuit. I will cover the basic rules that apply to each type circuit, starting with the series circuit.

(2) Rules that Pertain to the Series Circuits

(a) The first rule pertains to current in a series circuit.

1. The rule states that: In a series circuit, equal current flows in all parts of the circuit.

2. This simply means if you were to connect an ammeter to the circuit to measure current flow, as illustration in Figure 21, the reading would be the same in all parts of the circuit.

(b) There are several rules that pertain to voltage in a series circuit. The first of these states:

1. Figure 22 illustrates that voltage drop or loss across each component is in proportion of the resistance of that component.

Correct Flow in a Series Circuit
(Figure 21)

a. All components of automotive circuits offer a resistance to current flow in the circuit.

b. This means that if a voltmeter was connected across two components in a series circuit having different resistance values the voltage drops would be in direct proportion to the resistance of the individual components.

Voltage in a Series Circuit
(Figure 22)

c. The lower the resistance, the lower the voltage drop and the higher the resistance, the higher the voltage drop across the component.

2. The second rule that applies to voltage in a series circuit states that: The total of all voltage drops is equal to the applied voltage.

a. This means that if 24 volts are applied to a circuit having one or more components the total voltage used by the circuit would be the same as the applied voltage.

b. In Figure 22 the voltage drop would be 24 volts because voltage or electrical pressure must be expended to push current through the resistance of the circuit and components.

3. The last rule that pertains to voltage in a series circuit is: To determine the voltage drop across any one component in the circuit multiply the current flow in the circuit by the resistance of that component.

(c) The last rule pertaining to series circuits relates to resistance contained in the circuit and components.

1. There is only one rule pertaining to resistance. To find the total resistance in a series circuit add the resistance of each part or component in the circuit together.

2. This means if you were to measure the resistance at various points in a series circuit and add them together they would be equal to the total resistance of the circuit.

Resistance in a Series Circuit

(Figure 23)

(3) Rules that Pertain to a Parallel Circuit (Figure 24)

(a) The first rule we will discuss is the rule that applies to voltage.

1. This rule is quite simple and the easiest of all. It states: In a parallel circuit, equal voltage is applied to each branch in the circuit.

2. This simply means if the source voltage is 24 volts and you were to measure the voltage at each branch, the

voltage would be the same as the source voltage; in this case 24 volts.

Voltage in a Parallel Circuit
(Figure 24)

(b) Rule number two applies to current flow in a parallel circuit.

1. This rule states: In a parallel circuit, the total current flow is equal to the sum of the currents in the individual branches.

2. If you measured the current flow in a parallel circuit having two branches and there were 2 amps of current flow in each branch, the total current would be (2x2=4) four amps.

Current in a Parallel Circuit
(Figure 25)

(c) The third rule that pertains to parallel circuits is dealing with resistance. (Figure 6)

1. This rule states: In a parallel circuit, the effective resistance is equal to the applied voltage divided by the total current; it is always less than the lowest resistance in the current.

2. This means, if an ammeter was connected across a circuit having two components containing 4 ohms each, the effective resistance would be half that of one branch.

Resistance in a Parallel Circuit
(Figure 26)

(d) The rules apply to voltage drop and current flow in the individual branches.

1. The first rule pertains to voltage drop across components of each parallel branch.

a. The voltage drop across each parallel branch is the same as, or equal to, the voltage that is applied to each branch.

b. This means, regardless of the resistance of the components in a parallel branch, if you were to measure the voltage drop across each branch, the voltage indicated should be the same as the applied voltage.

2. The second rule pertains to current flow in components of each individual parallel branch.

a. The current flow in individual parallel branches is in direct proportion to the voltage applied to each branch and the resistance of that branch.

b. We know that the voltage applied to each parallel branch is the same, but the resistance of each branch can be different; therefore, the current flow through each branch will be in direct relationship to the resistance in that branch.

(4) Rules that Apply to the Combination Series-Parallel Circuit

(a) Although the same rules that apply to series and parallel circuits are applied to the series-parallel circuit, there are specific procedures to learn about applying the rules.

(b) The procedure for determining current flow in the series- parallel circuit is a little different from that previously explained.

1. (Figure 27) First the total effective resistance of the parallel part of the circuit must be determined.

2. Next, the total resistance in the series part of the circuit must be determined.

3. The resistance in the series part and the resistance

in the parallel portion of the circuit are added together to determine the total circuit resistance.

Resistance in a Series Parallel Circuit (Figure 27)

4. Having determined the total effective resistance of the circuit you can then determine the current flow.

(5) If you think about these rules in relationship to troubleshooting an automotive electrical circuit, you can see how they will help you determine why something doesn't work.

(a) For example, if voltage at the battery is adequate to run a particular device, but at the accessory itself voltage is inadequate, the resistance in the circuit between the device and source must be too high.

(b) In other words, the voltage drop is excessive. You can measure voltage drop over a part of a circuit by connecting a volmeter across that part of the circuit. Then if you know the amperage, you can calculate the resistance.

(c) On the other hand, if you measure resistance and amperage, you can calculate the voltage drop.